Research Article

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Self-sustainability of phosphorus cycle in rubber (*Hevea brasiliensis*) plantations: Annual recycling through litter and removal through latex

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Abstract

Low phosphorus availability is one of the main soil factors limiting forest productivity in tropical and subtropical regions. Rubber (*Hevea brasiliensis*) trees are predominantly cultivated in warm humid tropics and the self-sustainability of rubber plantation with respect to phosphorus nutrition was studied in a PB 217 plantation planted in 1984 and received phosphorus at various levels (0, 10, 20, 30 and 40 kg $ha^{-1}yr^{-1}$) from 1998 onwards. All the treatments received nitrogen and potassium uniformly at the rate of 30 kg $ha^{-1}yr^{-1}$. Before the commencement of the experiment all the trees were uniformly manured with nitrogen, phosphorus and potassium. Yield of latex, recycling of P through litter and removal through latex were quantified during 2003-04. Recycling and removal of other nutrients were also quantified. Yield of latex was not influenced by the levels of P applied. Content of P in litter and latex and quantity of litter added were also not influenced by the levels of P. Recycling and removal of other major and micronutrients were also comparable in all the treatments. Annual recycling of P through litter was marginally greater than removal through latex whereas, recycling of other nutrients was substantially higher than their export through latex. The data indicate the self-sustainability of P cycle in a mature rubber plantation adequately supplied with phosphorus during the actively growing phase.

Keywords: Hevea brasiliensis, nutrients, recycling, removal, sustainability

Introduction

Maintaining soil nutrient supply is crucial for sustaining productivity of tropical plantations. Many tropical plantations are planted with fast growing trees with short rotation cycles and there is a growing concern about the sustainability of these plantations. Long term nutrient supply and productivity of plantations are controlled by nutrient transformations through litter recycling and other input and output fluxes of nutrients. Though some of the industrial plantations are intensively managed with systematic manuring throughout their life cycle, some others are often left without fertilizer application after establishment and early growth. Nutrient addition and transformation through litter recycling plays a fundamental role in sustaining the fertility of these plantation soils.

Phosphorus is often reported to be the major limiting nutrient for productivity in tropical regions (Batjes, 1997; Drinkwater and Snapp, 2007). About 65 per cent of tropical soils are strongly P deficient and 27 per cent are moderately deficient (Goncalves *et al*., 1997). High P fixing capacity of these soils due to low pH and the predominance of ionic forms and hydrous oxides of Fe and Al promote fixation of native and added P and reduce P availability to plants. In India, 75 % of the traditional rubber growing areas (Kerala, parts of Tamil Nadu and Karnataka) is reported to be low in available P (NBSS and LUP, 1999).

Rubber (*Hevea brasiliensis*), a forest tree indigenous to the tropical rain forests of Central and South America is the only viable source of natural rubber. The tree has a life span of about 35 years under cultivated

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conditions. Biomass and nutrients are accumulated at a fast rate during the initial 4-5 years which is the active growing phase (Watson, 1989). After this period, rate of growth decreases and nutrient recycling through litter sets in. The tree is deciduous and sheds its leaves during December- January and refoliates after 2-3 weeks. The litter accumulates on the plantation floor and gets gradually decomposed releasing nutrients for subsequent uptake by the trees. Estimates of quantity of nutrients recycled through litter annually vary with the clone, age of the trees, planting density and agro climatic region. In Malaysia, Shorrocks (1965) reported an annual addition of 45 to 90 kg of N, 3 to 7 kg of P, 10 to 20 kg of K, 60 to 120 kg of Ca and 9 to 18 kg of Mg in one hectare of mature plantation. In Tripura (North East India), the reported quantities were 94 to 130 kg of N, 5 to 6 kg of P, 22 to 25 kg of K, 106 to 168 kg of Ca and 17 to 33 kg of Mg in a 14 year old RRIM plantation in one hectare (Verghese *et al*., 2001). In Brazil, the nutrients returned through litter fall were low, 22.4 kg N, 1.5 kg P, 1.9 kg K, 41.0 kg Ca and 8.2 kg Mg (Murbach *et al*., 2003) in one hectare of a 15 year old plantation of the same clone. After 6-7 years of growth, extraction of latex begins and is continued for 22 to 25 years in commercial plantations. Quantity of nutrients removed through latex varies with the yield and content of nutrients in the latex and in Sri Lanka, Samarappuli and Yogaratnam (1997) estimated an average annual removal of 9 kg N, 2 kg P, 8 kg K, and 2 kg Mg through 1400 kg of dry rubber. In Brazil, the quantities of nutrients exported through 1700 kg of dry rubber were comparatively low, 4.8, 1.9, 5.0, 1.4 and 0.4 kg N, P, K, Ca and Mg. The quantities of micronutrients removed were 9, 226, 672 and 53 g Cu, Fe, Mn and Zn from one hectare of rubber plantation in one year (Murbach *et al*., 2003).

Rubber plantations are considered to be closed ecosystems with a constant cycle of uptake and return of nutrients (Watson, 1989). Even though annual nutrient recycling through litter fall was quantified in a mature rubber plantation of clone RRIM 600. India by Verghese *et al*. (2001), net nutrient addition to the system after the nutrient export through latex was not quantified. In the present investigation, the P sustainability in a 17 year old rubber plantation of clone PB 217, was studied at various P levels in Central Kerala. The addition through litter fall and removal through latex of other major and micronutrients are also discussed.

Materials and Methods

The experiment was conducted in a private estate at Thodupuzha in Central Kerala (9^0 50’ N latitude and $76^0$48’ E longitude at an altitude of 115 m above mean sea level). Rubber trees (clone PB 217) were planted in 1984 at a spacing of 4.60 x 4.60 m. The soil of the experiment site was sandy clay loam and belonged to the order Ultisol, suborder Humult and the soil type was Ustic Kandihumults. The experiment was commenced during 1998. All the trees were supplied with nitrogen, phosphorus and potassium uniformly till the commencement of the experiment. The available P status of soil of the experiment area before the commencement of the experiment was 18.80 kg ha^{-1}. From 1998 onwards, trees were supplied with phosphorus at five levels (0,10, 20, 30 and 40 kg P_2O_5 ha^{-1} yr^{-1}). Rock phosphate (Rajphos) was applied as the carrier of P. In all the plots, nitrogen and potassium were applied uniformly (30 kg $ha^{-1}yr^{-1}$ each) as urea and muriate of potash. The experimental design was RBD with four replications. There were 36 trees in one plot. Fertilizers were applied in two equal splits during April-May and September-October. Observations were recorded during 2002-04.

Nutrient addition through litter fall

Litter addition in each plot was quantified with plastic nets of $1m^2$ size used as litter traps installed in the plots. They were set below the trees on wooden poles at a height of 30 cm from the ground. The quantity of litter collected in the traps was quantified at monthly intervals from February 2003 to January 2004 (from refoliation to wintering) and moisture content was determined by drying sub samples at 80^0 C.

The litter collected from each plot was pooled and samples were dried in a hot air oven at 80^0 C and analyzed for N, P, K, Ca, Mg, Fe, Mn, Zn and Cu at quarterly intervals. Nitrogen content of litter was determined by microkjeldahl method using a Nitrogen analyzer. Contents of other nutrients were determined by dry ashing as described by Piper (1966). Contents of P and K were determined using an autoanalyzer and that of other nutrients with the help of an atomic absorption spectrophotometer.

Nutrient removal through latex

Volume of latex and dry rubber content (DRC) were measured at monthly intervals. Latex samples were dried in the oven at 80° C and analysed for N, P, K, Ca, Mg, Fe, Mn, Zn and Cu (RRIM, 1973) at quarterly intervals from April onwards. Nutrient removal through latex was estimated from latex yield and nutrient content of the latex.

Soil nutrient status

Soil samples (0-30 cm) were analyzed for organic carbon, available N, available P, K, Mg, Fe, Mn, Zn and

Cu. Soil samples were mixed thoroughly, dried in the shade and sieved through 2 mm sieve before analyses. Organic carbon content of soil was determined by Walkley and Black's method (Jackson 1958). Soil available N content was extracted by KCl and determined by nitrogen analyzer (Jackson, 1958). Soil available P content was determined following Bray II extraction (Bray and Kurtz 1945) and chlorostannous reduced molybdophosphoric blue color method. Available K and exchangeable Ca and Mg were extracted with 1N ammonium acetate for determination. Content of DTPA extractable micronutrients was determined with the help of an atomic absorption spectrophotometer (Lindsay and Norwell, 1978).

Results and Discussion

Soil nutrient status

Rubber growing soils with available P status below 22.4 kg ha^{-1} is rated to be low in available P content (Krishnakumar and Potty, 1992) and in the present experiment it was 14.1 kg ha^{-1}, which is below the adequate level. With increasing P levels, soil P status increased (Table 1). Compared to other nutrients, loss of P from the soil is less and a part of the applied P gets accumulated in the soil. Different levels of P were imposed from 1998 onwards and after five years, there was a definite increase in P status particularly in treatments which received higher levels of P.

Table 1. Soil organic carbon, major and micronutrients at different P levels

P levels (kg ha^{-1})	OC (%)	Av.N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Ex.Ca (cmol kg^{1})	Ex. Mg (cmol kg^{-1})	DTPA extractable micronutrients (ppm)			
							Fe	Mn	Zn	Cu
0	1.16^{ns}	54.42	14.1^{a}	173.6^{ns}	0.20	0.08^{ns}	23.62^{a}	5.61^{a}	0.44^{ns}	5.44^{ns}
10	1.21^{ns}	51.59	24.2^{a}	130.2^{ns}	0.22	0.08^{ns}	18.37^{b}	5.56^{a}	0.37^{ns}	6.56^{ns}
20	1.18^{ns}	56.44	28.5^{a}	217.0^{ns}	0.27	0.09^{ns}	17.37^{b}	4.86^{a}	0.43^{ns}	6.36^{ns}
30	1.07^{ns}	48.36	52.8^{b}	145.6^{ns}	0.29	0.11^{ns}	17.16^{b}	3.30^{b}	0.34^{ns}	6.17^{ns}
40	1.08^{ns}	42.78	69.6^{b}	154.9^{ns}	0.27	0.11^{ns}	13.75^{c}	2.97^{b}	0.34^{ns}	5.81^{ns}
SE	0.10	8.63	5.6	25.3	0.02	0.01	1.10	0.45	0.06	0.80

Different letters indicate significant (P = 0.05) difference among treatments, ns = not significant

The organic carbon content was in the medium range and was not influenced by P levels. Large quantity of nutrients recycled every year through litter maintain or improve the organic matter content and rubber soils are generally reported to be rich in organic matter (Krishnakumar and Potty, 1992). The available N and K status of the soil were also comparable. Soil Ca and Mg contents were higher in P applied plots due to the addition of these nutrients through rock phosphate. Soil Fe status in control was significantly higher compared to the P applied treatments possibly due to the antagonism between Fe and P resulting in the lowering of DTPA extractable Fe content in these plots as suggested by Lucas and Knezek (1972). The lowest Fe content was observed in the highest P plot (13.75 ppm) and it was significantly lower than that of the other treatments. Phosphorus rates did not influence the DTPA extractable Zn and Cu content, whereas, Mn content decreased due to formation of phosphorus manganese complex as observed by Rao *et al*. (2002) in rubber growing soils.

Nutrient recycling through litter

Annual litter addition

Annual litter addition (excluding medium and large branches) ranged from 7.12 to 7.85 t ha^{-1} and was not influenced by P levels (Table 2). The clone tested was PB 217 and the litter input values were comparable with the reported values for clone RRIM 600 in North East India by Verghese *et al*. (2001), and higher than the estimated values in Malaysia and Sri Lanka. Estimate of litter fall in our study was several folds higher than the values reported for the clone RRIM 600 in Brazil by Murbach *et al*. (2003). Considering that the density of planting is higher in Brazil, this difference can only be partly explained by the variations in the agro climatic conditions of the study areas. Being deciduous in nature, the rubber tree sheds almost entire leaves during January and 54.40 % of the total litter input occurred during this period.

Table 2. Estimates of annual litter addition at various P levels in a 17 year old PB 217 plantation

P levels (kg ha^{-1})	Annual litter addition (t ha^{-1})	Litter addition during December-February (t ha^{-1})
0	7.12	3.72
10	7.49	4.44
20	7.80	3.50
30	7.79	4.37
40	7.85	4.52
SE	0.64	0.55
CD (P = 0.05)	NS	NS

NS = Not Significant

Nutrient content of litter

Among the nutrients, Ca was present in the highest quantity followed by N and K. There was no appreciable difference between treatments with respect to the content of nutrients (Fig. 1). As the season advanced, litter N content showed an increase followed by a decline and lowest content was observed during January which corresponds to the leaf shedding period. Litter P content showed more or less a steady decline till the leaf shedding period. Litter K content was the lowest in July and then increased steadily. July is a heavy rainfall period and the lower litter K content during this period might be due

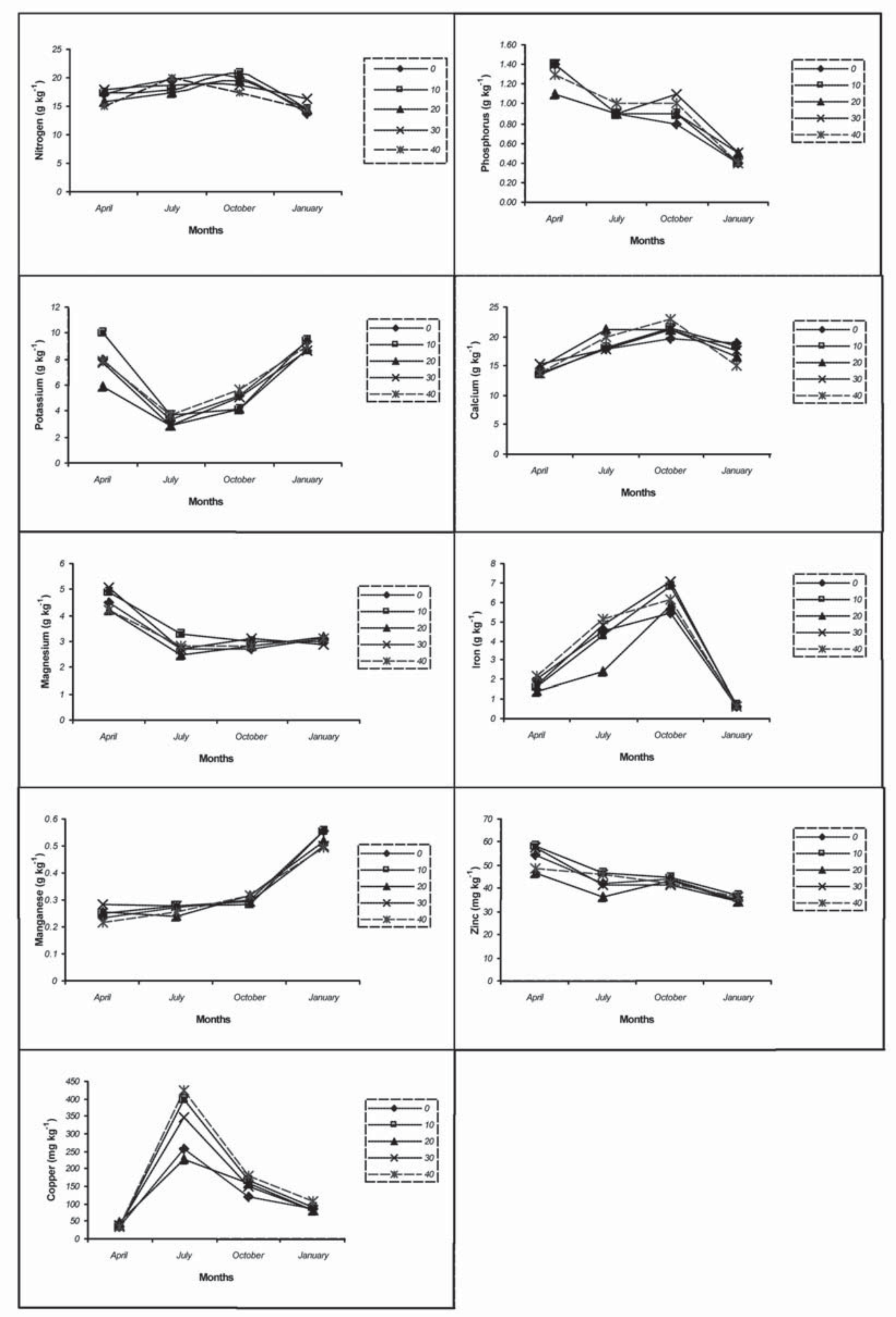

Fig. 1. Seasonal Pattern of nutrient concentrations in litter at different Phosphorus levels in a 17 year old PB 217 plantation

the leaching of K from litter. The subsequent increase might be to maintain the sink strength of water of senescent leaves to provide the appropriate cell hydration to conduct senescence as suggested by Milla *et al*. (2005). Litter Ca and Zn content did not show much seasonal variation. Magnesium content was higher during April and then declined as the season advanced. Fe content was the lowest during January whereas, Mn content was the highest. Aerial spraying of copper fungicide is practiced against abnormal leaf fall disease in May and this might explain the high Cu content in the litter during July.

Nutrient addition through litter

Calcium and N are the nutrients recycled through litter fall in larger amounts as reported earlier (Shorrocks, 1965; Verghese *et al*., 2001; Murbach *et al*., 2003). Recycling of P through litter in the control plot was comparable with those received lower levels of P (Table 3). Phosphorus rates did not influence the recycling of other nutrients. The quantities of nutrients returned through litter fall vary widely in different countries, the lowest in Brazil followed by Malaysia and India. This difference can be expected due the large variation in the quantities of litter fall in different countries. Nutrient recycling through litter fall was comparable with the quantities reported in N.E. India for clone RRIM 600 by Verghese *et al*. (2001), except in the case of K and Mg. The return of K and Mg to soil through litter fall in N.E. India ranged from 22 to 25 and 17 to 33 kg $ha^{-1}yr^{-1}$, respectively, whereas the corresponding values were 57.14 and 14.85 kg $ha^{-1}yr^{-1}$ in our experiment. This difference can be attributed to the lower K and higher Mg contents of litter in N.E. India which might possibly due to the clonal difference as suggested earlier by Pushparajah (1979). Rubber growing soils are highly acidic and rich in Fe and Al and have a low percentage of exchangeable bases especially in the upper horizon, which is attributed to the leaching of appreciable quantities of cations due to heavy rainfall (Krishnakumar and Potty, 1992). Addition of large quantities of Ca through litter is vital due to its role in maintaining the level of exchangeable bases and alleviating Al toxicity. Among the micronutrients, recycling of Fe was the highest (15.5 to 18.05 kg $ha^{-1}yr^{-1}$) and that of zinc was the lowest (0.28 to 0.32 kg ha^{-1} yr^{-1}). The recycling of Mn ranged from 2.91 to 3.29 kg ha^{-1} yr^{-1} and Cu from 0.74 to 0.89 kg ha^{-1} yr^{-1}. The recycling of various nutrients was directly related to their respective contents in the litter. Though there was significant difference in soil Ca, Fe and Mn status between the treatments, it was not reflected in their respective contents in the litter or annual recycling.

Table 3. Annual return of nutrients through litter fall (kg ha^{-1}) to soil at different P levels in a 17 year old PB 217 plantation

P levels (kg ha^{-1})	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
0	114.2	4.8ab	53.6	127.83	12.64	15.6	2.9	0.29	0.77
10	124.3	5.1ab	61.3	133.68	17.16	15.51	3.3	0.32	0.89
20	124.7	5.1ab	54.3	145.86	15.43	17.3	3.2	0.28	0.85
30	134.7	5.9bc	56.4	135.11	13.93	18.0	3.1	0.31	0.74
40	124.3	5.9bc	60.1	128.36	15.09	18.1	3.1	0.31	0.77
SE	9.95	0.25	5.3	11.94	1.78	1.84	0.31	0.02	0.05
CD (P = 0.05)	NS	0.77	NS	NS	NS	NS	NS	NS	NS

Different letters indicate significant difference among treatments
NS = Not significant

Nutrient removal through latex

Latex yield and nutrient content of latex

Yield of latex was not influenced by P levels (Table 4). Earlier workers have reported that during the early years of the plantation, application of P fertilizers improved growth of rubber (Pushparajah, 1969; Punnoose *et al*.,1975). After five years, lack of consistent response to P application in tree growth and latex yield was observed in many experiments. (Pushparajah 1969; Lim 1977; Pushpadas *et al*., 1979; RRII, 2000). Pushpadas *et al*. (1979) suggested that trees could be meeting their P requirement from the organic forms

Table 4. Annual latex yield and nutrient removal through latex at various P levels in a 17 year old PB 217 plantation

P levels (kg ha^{-1})	Yield (kg $ha^{-1}yr^{-1}$)	N	P	K	Mg	Ca	Fe	Mn	Zn	Cu
		(kg ha^{-1} yr^{-1})				(g ha^{-1} yr^{-1})				
0	2316.6	13.9	4.3	13.1	3.3	28.2	20.4	1.5	10.8	11.3
10	2515.0	15.0	4.4	13.8	3.8	29.7	20.6	1.6	11.0	10.6s
20	2367.4	14.1	4.6	13.3	3.2	27.8	18.7	1.4	10.5	10.1
30	2353.2	15.2	4.8	13.9	3.6	29.1	24.1	1.6	11.4	13.2
40	2217.1	12.9	4.3	12.2	3.0	23.6	19.9	1.3	9.7	12.2
SE	158.6	0.60	0.33	0.89	0.24	1.85	1.22	0.08	0.76	0.85
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Not significant

resulting from cover crop residues and leaf litter. Though beneficial effect of P is often not observed on either tree growth or latex yield, it has an important role in biosynthesis of latex which is a high energy absorbing process. Inorganic phosphorus in latex reflects the energy metabolism and is necessary for the production of nucleic acids required in rubber biosynthesis (Jacob *et al*., 1982). Phosphorus is also essential for a balanced Mg/P ratio in latex which influences the stability of latex (Philpot and Westgarth, 1953).

The content of P and other nutrients in the latex was not influenced by P rates (Fig. 2) Among the different nutrients, N was present in the highest quantity and Mn in the lowest quantity in the latex. Appreciable seasonal

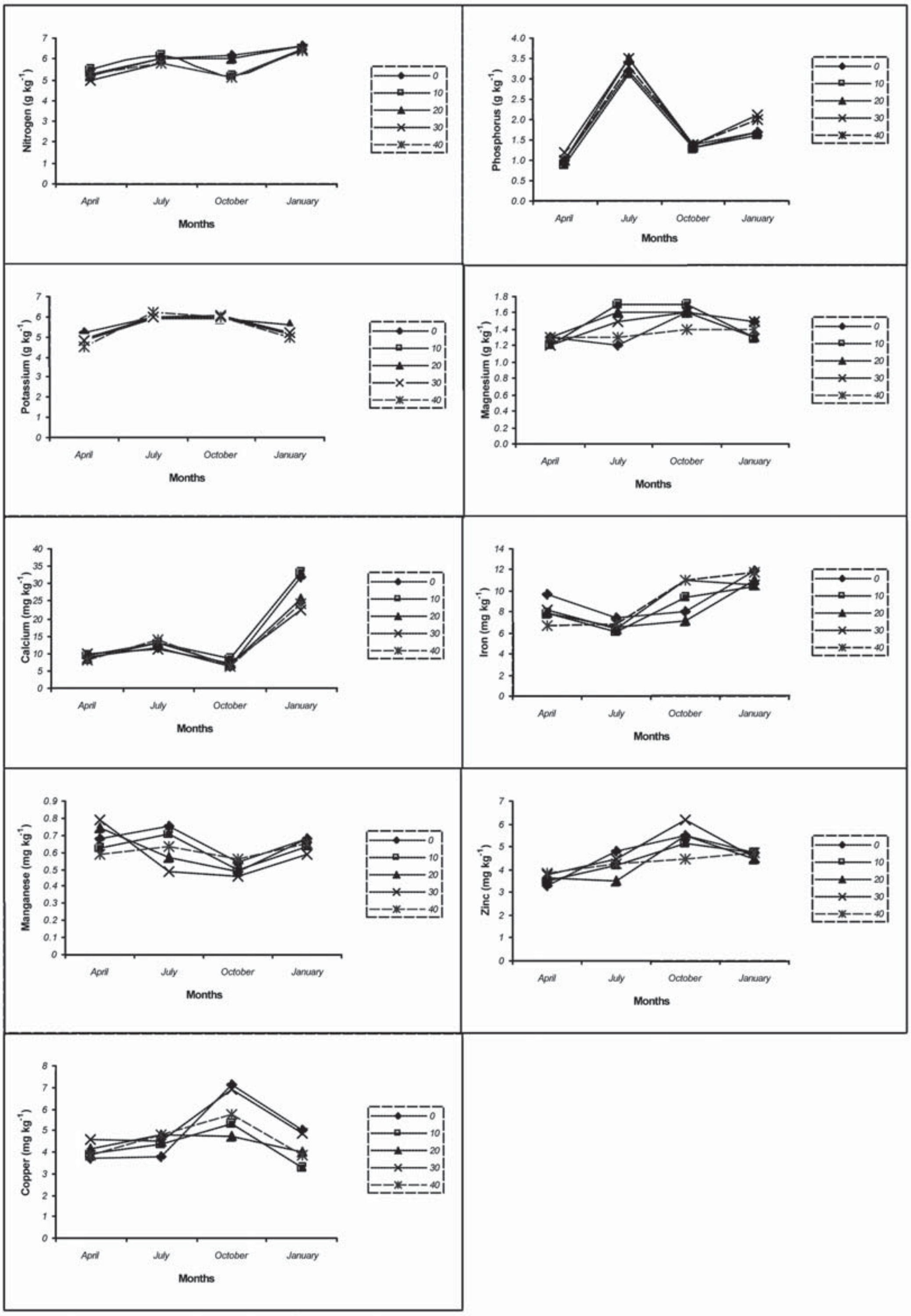

Fig. 2. Seasonal Pattern of nutrient concentrations in latex at different Phosphorus levels in a 17 year old PB 217 plantation

variation was observed in the case of latex phosphorus content, higher values observed during July might be due to higher metabolic activity of latex leading to higher yield during this period. A positive correlation between latex yield and inorganic P content was earlier reported by Simon (2003). Latex Ca content also showed seasonal variation, and it was higher in January possibly due to low volume of latex following wintering during this period.

Nutrient export through latex

Phosphorus rates did not influence the quantity of major and micro nutrients removed through latex (Table 4). Compared to the annual nutrient transformations through litter recycling, nutrient removal through latex is very low, in the case of all the nutrients except P**.** Nutrient export through latex depends on yield and latex nutrient content, and in the present experiment, latex yield ranged from 2,217 to 2,515 kg $ha^{-1}yr^{-1}$, higher than the latex yield in other latex removal studies in Sri Lanka and Brazil. Among the nutrients, N was removed in the largest quantity (12.9 to 15.2 kg ha^{-1}) followed by K (12.2 to 13.8 kg ha^{-1}). Removal of P ranged from 4.26 to 4.81 kg $ha^{-1}yr^{-1}$. The estimated quantities of nutrient export through latex by Samarappuli and Yogaratnam (1997) from one hectare were lower in Sri Lanka **(**9 kg N, 2 kg P, 8 kg K, and 2 kg Mg through 1400 kg of dry rubber) and this can be attributed to the lower yield ha^{-1} of trees in Sri Lanka. In Brazil, the values reported for major nutrients by Murbach *et al*. (2003) were still lower, which is due to the lower latex nutrient content in Brazil, possibly due to the clonal difference in the nutrient content of latex.

Annual phosphorus balance under varying levels of P application

While calculating the annual P balance, the annual recycling through litter and removal through latex were only considered in our study. The other fluxes of P in to and out of the system were not considered. Adequate P fertilizers were applied during the active growing phase of rubber and was withheld during the yielding phase only. Recycling of P through litter was marginally higher than removal through latex even in the control indicating the self sustainability of P cycle in a mature PB 217 plantation (Fig. 3). The results of the experiment partly explain the lack of response of rubber trees to phosphorus application as earlier reported.

Conclusions

With increasing phosphorus levels, soil available P status increased. Phosphorus rates did not influence litter input and latex yield. The content of P in litter or latex was also not influenced. Even in the control, annual P recycling through litter was marginally higher than removal through latex. Annual recycling of other major and micronutrients was substantially higher than their export through latex. Results indicated the self sustainability of P cycle in a yielding PB 217 plantation.

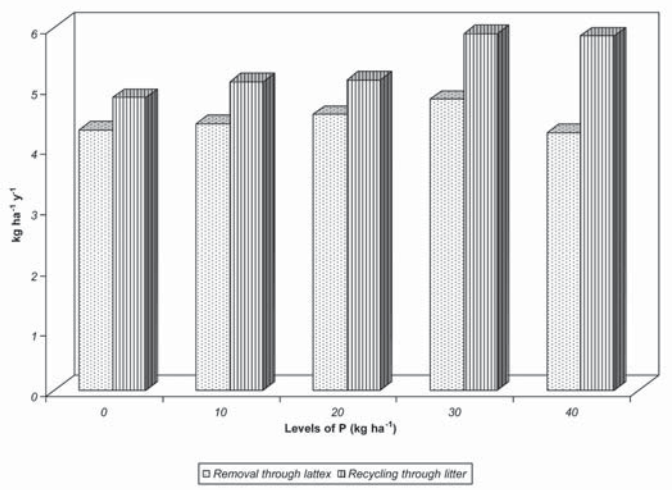

Fig. 3. Annual P balance in a 17 year old rubber plantations at different P levels

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